

Locality in Language and Locality in Brain Oscillatory Structures

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From the perspective of brain oscillations, an explanation is offered as to why external systems of language cannot deal with identical categorial elements in certain local domains. An equivalent locality effect in brain structure is argued for which causes a (cognitively problematic and ambiguous) synchronization of rhythms in the *gamma*, *beta1*, and *beta2* bands. These rhythms can be related to different categories, and their limited patterns and interactions may explain syntactic constraints on phrases, phases, and Internal Merge.

Keywords: brain oscillations; constraints; dynamics; labeling; locality

1 Introduction and Background

One of the most extensively investigated issues in linguistics is locality: Operations take place within concrete domains or chunks of structure, which is manifested in turn by the cyclicity of the derivation. At first glance, two kinds of locality constraints are discernible in language: within domains, or short-distance, and across domains, or long-distance. However, the cyclicity of operations like Internal Merge (IM, traditionally known as movement) makes it possible to reduce constraints across domains, keeping them within. These domains could be phrases or phases; in fact, there are recent studies which argue that phrases and phases are very close to each other (Epstein & Seely 2002, Müller 2004) and strongly correlated to projection or labeling (Narita 2012, Boeckx 2014a).

Inspired by Boeckx (2008) and his unification of the products of External Merge (EM) and IM, where projection is treated equally in phrases and chains, I offer an explanation about combinatorial or interpretative constraints within (and apparently across) locality domains, in a phase-like fashion, from a single logic. Concretely, the constraints will be couched in terms of brain oscillations (Buzsáki 2006), roughly: They arise from the limited oscillatory patterns that

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certain local brain structures can sustain. This is a first expansion of the research first and originally presented in Ramírez (2014).

Brain oscillations are the emergent mechanism by which brain activity is self-organized (Buzsáki 2006). Biophysical properties of brain components and their interactions locally and globally submit brain activity to rhythmic patterns, as reflected by electroencephalographies and magnetoencephalographies (see chapter 4 of Buzsáki 2006 for an overview about recording methods). At different spatial scales, periods of high activity resulting from the synchrony of neural excitation—within milliseconds time windows—alternate with periods of low activity produced by coordinated inhibition. Such phases enable, respectively, the integration and segregation of information, forming assemblies (Hebb 1949) both at the level of coherent representations (Gray & Singer 1989, Engel & Singer 2001) and transient networks (Fries 2005). There is not a unique brain oscillation but a huge amount at multiple frequencies ranging from .05Hz to 500Hz (Buzsáki & Draguhn 2004). The most popular bands are *delta* (1-4Hz), *theta* (4-7Hz), *alpha* (8-14Hz), *beta* (15-29Hz), and *gamma* (30-90Hz).

The principles governing these oscillations can be explanatory regarding locality. From a cognitive perspective, the constraints are roughly reflected by a conflict at the 'external systems' interpreting *XX-like constructions. We will name this phenomenon 'anti-identity', based on the work of Richards (2010) and Boeckx (2014a). Intra-phasally, these authors note that phase complements cannot contain two identical categorial elements (2). However, this can also be reflected by selection constraints within phrases (1).¹

- (1) a. *John *v* [eat [apples] [oranges]].
 b. * [... [John] [Mary] *v* [eat apples]].
 c. * V X X / X X V
- (2) a. *sono [queste foto del muro] [la causa della rivolta]. *Italian*
are these pictures of-the wall the cause of-the riot
 'These pictures of the wall are the cause of the riot'.
 (adapted from Moro 2000)
- b. *Describieron [a un maestro de zen] [al papa]. *Spanish*
described to a master of zen to-the pope
 'They described a Zen master to the pope'.
 (adapted from Boeckx 2008)
- c. * V X X

Similarly, Grohmann (2000, 2011) points to an "anti-locality" constraint (3), which, very roughly, bans (movement) dependencies in local chunks of structure that are transferred to the external systems (unless repaired later by a sort of spell-out mechanism). Despite their similarity to phases at first glance, Grohmann (2011) restricts these chunks to 'Prolific Domains' where thematic, agreement and discourse relationships are established (which would correspond to *v*P, TP, and CP).

¹ For expository purposes, I keep the structural details to a minimum, especially because the assumption of an exoskeletal labeling mechanism (Boeckx 2014a) would introduce structures that generative tradition is not very familiar with. The main interest lies in identifying the coexistence of similar elements.

- (3) a. *... T ... [John_i likes t_i].²

(adapted from Grohmann 2011)

- b. * [X V X]

To put it in broad terms, depending on whether the local domain (3) is considered VP or *v*P (see Larson 1988, Hale & Keyser 1993), at least two kinds of anti-locality can be defended. As discussed by Grohmann (2011), a more classical approach to anti-locality takes the relevant domain to be XP, so intra-phrasally there is a maximum of one occurrence of each element. In contrast, a more recent approach, consistent with Grohmann's particular perspective, takes the relevant domain to be larger, so there is a maximum of an occurrence of each element within each prolific domain.

A third approach would consist of defending that the relevant domain in (3) is a phase complement, which would bring anti-locality and anti-identity very close to each other. However, a more elegant idea, a truly attractive one, is to unify these three possibilities, arguing that the relevant domain in (3) is at the same time a phrase and a phase, which in turn corresponds to the interpretatively coherent units at the interfaces that Grohmann's Prolific Domains define.

In this respect, Grohmann (2011) remarks the appeal of fusing 'standard' locality with 'anti-locality' domains, although this would be "by no means necessary". Nevertheless, to deepen our understanding of these strikingly similar locality phenomena, such unification may be "by all means necessary". For space reasons, I will not go into details, but it should be noted that the arguments against such unification are rather weak. It has been argued that intra-phrasal anti-locality is redundantly barred by Last Resort considerations or a ban on vacuous operations; however, given the present assumption that Merge is free and the abuse of feature-driven explanations (Boeckx 2014a), these counterarguments lose their strength. Besides, it has been argued that Prolific Domains differ from phases in that the first are three, whereas the latter only two (*v*P and CP); in spite of that, phases begin to be related to deeper requisites for syntactic derivations (Boeckx 2014a), providing a category-neutral definition of them rather than recasting old concepts of barrier nodes (Boeckx & Grohmann 2007b).³ Finally, Müller (2004, 2011) argued for an unification of phrases and phases, and for a reformulation of the Phase Impenetrability Condition (Chomsky 2000, 2001), in phrasal terms. This approach is based, among other reasons, on the lack of correspondence between spell-out domains and classical Chomskyan phases, and the successive cyclic movement through every phrase edge (Boeckx 2003), as reflected by morphological side-effects, reconstruction operations, etc. Even though one may think that Müller's (2004, 2011) approach suffers from 'featuritis' (Boeckx 2010) and that constraints such as Ph(r)ase Balance (Heck & Müller 2000, Müller 2004) may not be so persuasive, I think that defining (anti-)local domains as phrasal provides us at least with a theoretically superior alternative (see Boeckx 2007). In sum, it is not illogical to analyze anti-locality in the same terms that anti-identity is approached in the present article.

² Classical movement traces are adopted only for expository purposes.

³ As a matter of fact, Grohmann (2011) discusses the possibility that some verbal Prolific Domains may be nominalized. Such expansion is similar to the one suffered by phases once a more category-neutral definition of them is defended.

(4) a. How do you think [he *v* [behaved (how)]]?
 (adapted from Rizzi 2011)
 b. *How do [who *v* [behaved (how)]]?
 c. V [...X... [...X...]]

To explain all the apparently distinct constraints above from a single principle in classical language subareas, it is needed to equate what seems to be locality across domains to locality within domains. For cases like (4), the cyclic nature of IM allows us to extend the *XX constraint we see in phase complements (2) to IM (3), as Chomsky (2013) points towards. Thus, as (5) shows, both elements involved in the apparent inter-phasal restriction are *not* in different domains when the constraint actually applies.

- [illegible]

Both intra- and apparent inter-domain constraints can be considered, then, as local limitations of merge or intolerance for ambiguity (Boeckx 2014a) in external systems. Next, on the premise that (linguistic) cognition is constructed over brain rhythms (Buzsáki 2006, Boeckx & Benítez-Burraco 2014), it makes sense to argue that locality effects in language arise from locality effects in brain structures over brain oscillations. Developing Boeckx’s (2013: 10) idea that anti-identity constraints “may result from constraints imposed by how many distinct rhythms the brain can couple in particular activities”, I argue that an ambiguous synchronization of rhythms in the *gamma-beta* bands, due to a locality effect of the sub-regions in classical language areas (at the periphery), leads to anti-identity effects on a cognitive level. However, this effect may not hold at the large-scale core language network, where the hippocampus, the thalamus, and the basal ganglia, with their canonical

theta, *alpha*, and *beta* rhythms, respectively, may enable neural syntax (Buzsáki 2010, Buzsáki & Watson 2012) of a higher complexity (Ramírez *et al.* 2015).

A review of the cognitive neuroscience literature will suggest that non-Phase Heads (PHs) may oscillate at *gamma*, that transitive PHs—those with complex complements Boeckx (2014a)—would do so at *beta2*, and that intransitive PHs—those with singleton complements—oscillate at *beta1*. In fact, this triangle represents the three elements of phrases/phases: complement, head, and specifier/edge. In like manner, a review of the theoretical linguistics literature will suggest that intransitive PH, specifiers and internally merged elements might be unified, in the present model, under the same *beta1* categorial rhythm. This will allow us to explain constraints on ph(r)ase structure and movement across domains in the same terms used intra-ph(r)asally. Finally, some space will be devoted to constraints on adjunction and alternatives to the proposed implementation.

To explain the constraints that cause these linguistic properties, I will develop the idea that regions of peripheral systems that interpret the three kinds of items listed above can only sustain a maximum of one rhythm for each of their respective bands. This is so because the structure would be too small to sustain them separately if multiple rhythms were to be initially generated. Since synchrony in the same band becomes mandatory and each band identifies an elementary category, multiple elements of the same type can neither be differentiated nor properly computed in each domain/cycle of the derivation.

Thus, locality effects in language emerge from locality effects on brain activity in relatively small populations of neurons, and ambiguity in linguistic structure is the result of ambiguity in the sustainment of brain oscillations which are responsible for, among other things, identifying elements. Pursuing this kind of research in what has been named by Kopell *et al.* (2014) the ‘dynamics’ framework, we are getting closer to reaching the implementational level of Marr (1982). In this sense, we might be able to explain why cognition has certain properties and not others from the physiological constraints of the circuits that generate it. This might be an adequate response to the kind of why question advocated in the minimalist program (Chomsky 1995): Why do we have the above-listed properties of cognition? Our answer is that we have them because we have those possible patterns of interactions in neural syntax, and not others.

Furthermore, as will be discussed, such an explanation reflects a lax interpretation of Chomsky’s (1986) distinction between I-language in the core and E-language in the periphery, and discusses the computational potential in terms of whether or not subcortical sources of slower rhythms are recruited. Finally, this same constraint explained at the meso-scale brain activity level is applicable to other cognitive domains. Along this line, it offers an alternative view to the limitations of cognitive neuroscience in studies of working memory, consciousness, or attention. If our hypotheses are on the right track, the core rather than the periphery of regions constrains the capacities of the system as well.

2 Labeling Elements by Oscillatory Bands

I assume Boeckx's (2014a) elementary categorization and develop his suggestion that elements are identified as a function of the concrete rhythm that forms and sustains their neural assemblies (Boeckx 2013). A first division can be done by claiming that non-PHs are sustained by *gamma* oscillations and PHs by *beta* oscillations. Furthermore, among PHs, two *beta* sub-bands may implement transitive and intransitive PHs: *beta2* and *beta1*, respectively. As discussed below, intransitive PHs bear appealing resemblances to specifiers and internally merged elements, which prompts one to consider them as a single elementary category. The latter unification, in turn, will extend the explanatory reach considerably, but at the expense of some empirical reach.

These three rhythms are those sustained canonically by the cortex (Roopun *et al.* 2006, 2008). With layer 4 acting as a frontier (Maier *et al.* 2010), *gamma* is mainly registered in supragranular layers, *beta2* in infragranular layers, and *beta1* emerges from the interaction of both infragranular and supragranular layers in certain circumstances as described below. Furthermore, the layered dynamics distinction is reinforced by anatomic connections and the direction of the flow of information from these areas: Supragranular layers connect primarily with higher areas in a feedforward manner, whereas infragranular layers send feedback to the first and connect with subcortical structures such as the thalamus (Douglas & Martin 2004, Bastos *et al.* 2012, Miller & Buschman 2013). Finally, different bands are discretized by different precise scales: A logarithmic scale around 2.16 that differentiates bands (Buzsáki 2006) allows us to potentially differentiate two categories in the *low beta-gamma* range, which would correspond to PHs and non-PHs, whereas a further discretizing golden mean of around 1.6 (Roopun *et al.* 2008) offers us a new categorical distinction within the *beta* range: transitive PHs for high and intransitive PHs for low *beta*. In short, the cortex offers anatomical, dynamic, information-dealing and "mathematical" reflections of that ternary categorical distinction.

2.1 Unifying Intransitive PHs, Specifiers, and IMed elements

Before moving to specific labeling using oscillations, the extension of the categorical rhythm *beta1* of intransitive PHs to specifiers and internally merged elements must be justified to some degree. First, an attempt will be done to unify specifiers and internally merged elements. Afterwards, they will be unified with intransitive PHs.

From a more cognitive point of view, one interpretation of Uriagereka's (1999) multiple Spell-Out model is that specifiers are always derived in parallel to the clausal spine. Although their fusion to the spine, cannot be strictly considered a case of IM, because the structure generated as a specifier is not contained in the spine, I argue that such a combination bears significant resemblances to the (sub)processes of IM. In this respect, IM has been theorized as being decomposed in copy and remerging (Corver & Nunes 2007).⁴ If we envisage the copy mecha-

⁴ One reviewer points to "more recent formulations under which IM is simply Merge and Label". However, the theoretical option of copy+remerge adopted here is more akin to the model under development. In my opinion, the hypothesis most prone to an interdisciplinary approach should be favored. At any rate, I only sketch a guideline subject to reformulations, not aiming to be conclusive.

nism as a more substantial availability in memory, with certain independence from its derivational history, this may be a feature required both by specifiers and internally merged elements. Being derived in parallel as a specifier may require that elements be available longer than usual before being coupled to the clausal spine; this is also the case for internally merged elements which are susceptible to merging operations longer. Independence from the derivational history may be reflected by the opacity of specifiers and moved elements for sub-extraction.

That copy-like mechanism, consisting of a longer holding in working memory, is a defining feature of the genesis and sustainment of *beta1* oscillations (see below). Thus, at least to a certain point, we can abstract significant commonalities between specifiers and internally merged elements, converging on the attributes of the *beta1* rhythm. This hypothesis makes further sense if we consider the position where internally merged elements land: It is always a specifier-like position, which is also the case for the edge in phases.

The next step to confer plausibility to the intended unification is to find significant commonalities between specifiers/internally merged elements and intransitive phases. In this respect, Boeckx (2014a) argues that specifiers are always intransitive phases, which is what prevents external systems suffering an anti-identity violation, where the combination of the PH of the current derivational stage and the PH merged to its edge takes place. As a matter of fact, in Boeckx's (2014a) theory, there is only one intransitive PH in each derivation apart from the specifiers, which is the one precisely at the bottom of the structure (consider how problematic that derivational point has always been in terms of labeling, etc.).

This not only equates intransitive PH and specifiers to a certain degree (and, by extension, internally merged elements), but also discards the other structures (adjuncts) derived in parallel that could be related to *beta1* as well. Boeckx (2014a) argues that adjuncts are transitive PHs that lead to anti-identity violations in their merge and from which islands, due to a forced transfer, could arise. Furthermore, the aforementioned fact that intransitive heads are those that initiate the derivation significantly connects with how that *beta1* rhythm is evoked: to be exact, by novel/unfamiliar elements, which can be interpreted as the beginning of each (parallel) derivation.

2.2 *Rhythmic Gamma, Beta2, and Beta1 Labels*

The purpose of this section is to justify why these specific rhythms are assigned to their concrete categories. Regarding non-PHs, the essential idea is that they are objects with less combinatorial potential or are simpler. I attribute *gamma* to non-PHs by considering the formation of neural words from Buzsáki's (2010) theory of neural syntax and the role *gamma* plays in binding features into coherent objects, which could be concepts lexicalized later (Buzsáki 2006, Bosman *et al.* 2014, Honkanen *et al.* 2014).

The observation that there is an increase of *gamma* activity as more items are represented or held (Roux & Uhlhaas 2014) suggests that *gamma* represents the contents of working memory (Honkanen *et al.* 2014) as well as items in language (see discussion below on the disambiguation of *gamma* and *beta* roles). Furthermore, *gamma* oscillations are supposed to sustain more local operations due to conduc-

tion delays (von Stein & Sarnthein 2000, Buzsáki 2006), all of which connects to their simplified nature with respect to *beta* PHs.⁵

The main property of PHs is that, due to a longer syntactic life, they are more complex than non-PHs in the sense that they act as linkers between themselves and among derivational stages. Such a complexity difference between *gamma* and *beta* has already been shown by Honkanen *et al.* (2014) in the representation of objects in visual working memory, with the more complex being represented by *beta* as opposed to *gamma*. Furthermore, in implementational terms, further complexity may also require the recruitment of a larger neural population, which is in line with the slowing down of *gamma* rhythms until they reach *beta* once PHs are labeled.

I attribute *beta* to PHs by taking into account the functional role of sustaining the *status quo* attributed to the rhythm in working memory (Engel & Fries 2010). Although there is ambiguity in the literature about *gamma* and *beta* in the function of holding items (Dipoppa & Gutkin 2013), there is accumulating evidence to ultimately disambiguate it, and to claim that only *beta* is the rhythm responsible for holding objects (Tallon-Baudry *et al.* 2004, Deiber *et al.* 2007, Engel & Fries 2010, Parnaudeau *et al.* 2013, Salazar *et al.* 2012, Martin & Ravel 2014), whereas *gamma* forms them initially. What defines PHs is that they have a longer merging life, which particularly enables them to be related to more elements. This is visible in the construction of the clausal spine over PHs embedding complements, where PHs function as links between different derivational phases and local domains—they remain at the edge, which enables them to be in at least two phases. Thus, it makes sense that PHs must be cognitive sets held longer in working memory by means of *beta*, which might be the capacity that allows us to transcend the computational complexity of finite state machines (Chomsky 1957).

In addition, the phase-edge presents a computational requirement that has also been noted in goal-directed behavior. One of the functions of PHs remaining at the edge when transfer takes place is to integrate the results of different derivational stages, as heads in phrases integrate complements and specifiers, which, as defended, might be the same case. Equally, Duncan (2013) argues that complex tasks are divided into hierarchically organized sub-goals, which he considers attentional episodes and which must be executed in the proper sequence to accomplish the final objective. Thus, both in the phase-edge and in the succession of attentional episodes, the results of one sub-process must be communicated to the next. Crucially, it is assumed that these kinds of processes require top-down control, which is a mechanism usually attributed to *beta* bands (Bastos *et al.* 2015).

The latter argument in favor of *beta*-holding PHs has to do with basal ganglia implications. Namely, that *beta* holding in memory mechanism can be understood as a selection mechanism provided by the basal ganglia, typically explained as one of its loops being disinhibited, thus favoring one (motor) representation at the expense of others (Koziol *et al.* 2009). Cannon *et al.* (2014) and Antzoulatos & Miller (2014) point to basal ganglia precisely as a cortical *beta* generator which, when added to evolutionary considerations (Buzsáki *et al.* 2013), suggests embrac-

⁵ The consistencies with cognitive neuroscience are stronger in Ramírez *et al.*'s (2015) model. Following Boeckx's (2014a) labeling by phase theory, it is argued that all items are born as *gamma* assemblies, and only some of them later become more complicated and are identified by *beta* as PHs. This is due to their derivational history, which is a longer coupling to a merging *alpha* rhythm and a delayed synchronization to a transfer *theta* rhythm.

ing Maier *et al.*'s (2010) hypothesis that subcortical rhythmogenesis of slow rhythms are detected in infragranular cortical layers. Thus, a coherent picture emerges with respect to PHs where basal ganglia, infragranular cortex, *beta*, and holding elements converge on a single mechanism.

Now, a further distinction among PHs can be made: *beta2* for transitive PHs and *beta1* for intransitive PHs (specifiers/internally merged elements). This could also help to disambiguate, in Cannon *et al.*'s (2014: 714) terms, the "mystery of multiple *beta* rhythms". The strongest arguments I can provide are threefold: (i) related to the fact that intransitive PHs are the beginning of each derivation and *beta1* is caused by unfamiliar or novel elements, (ii) related to what has been described as one sub-process of movement, *beta1* genesis occurs from previous *beta2* and *gamma*, in a copy-like fashion, and (iii) related to the longer syntactic availability of intransitive PHs, moved elements and specifiers, *beta1* presents the capacity to sustain representations in absence of inputs. Now, each of these points will be developed.

First, Kopell *et al.* (2010) note that *beta1* rhythm is unchained by unfamiliar, as opposed to familiar, elements. The first can be reinterpreted as novel elements and extended to those initiating a new process. Similarly, Boeckx (2014a) argues that intransitive PHs are those that always initiate the derivation. This strikes me as highly similar, that is to say, the novelty of both PHs and unfamiliar elements. Considering the discussion above, if phase heads are sustained by *beta*, it makes sense to think that the more novel process has to do with the initiation of the derivation and, therefore, unchains *beta1*.⁶

Second, with regard to the copy sub-process of movement, *beta1* genesis may shed light on the issue. *Beta1* rhythm emerges when a period of high excitation decays, and *gamma* in supragranular layers and *beta2* in infragranular layers begin to interact and reset each other (Kramer *et al.* 2008). The result of that interaction, which implies a transient 'fusion' of supragranular and infragranular layers, is that their phases are added up: "[T]he period [of *beta1*] (65 ms) is the sum of the natural periods (25 ms [of *gamma*] and 40 ms [of *beta2*]) of the excitable oscillators" (Kramer *et al.* 2008: 2) (see also Roopun *et al.* 2008). For that *beta1* rhythm to arise, then, the "initial interval of coexistent *gamma* and *beta2*" preceding the new oscillation is crucial (Kramer *et al.* 2008: 2).

If labeling PHs is obtained by slowing down the rhythm that initially sustained the assembly of the item from *gamma* to *beta*, what *beta1* genesis suggests would be a second labeling after the first one, a sort of dual process. In the first step, the initial part of the process would be when the assembly that represents the externally merged PH oscillates at *beta2* in the period of high excitation, and the supragranular layers at *gamma* receive a kind of feedback or top-down signal as *beta2* in the infragranular cortex. Later, when excitation decays, a second labeling-like operation would take place. Thus, the second part of the process would be a slowing down of the assembly and the fusing of the infragranular and supragranular layers into a single *beta1* rhythm. That latter sub-process as a sort of copy/second labeling is strikingly similar to the decomposition of movement operation in early minimalism (Chomsky 1993): Merge and label initially the PH using *beta2* and then copy it using *beta1*.

⁶ Furthermore, this makes sense when taking into account that *beta1* arises from the decay of a strong excitation, which might be caused by the awaking of the network by way of bursts.

As discussed above, intransitive PHs, moved elements, and specifiers are closely related: If specifiers are derived in parallel, then maybe what is actually embedded in the clausal spine is really a copy of their PH which, as discussed, is certainly the case for intransitives. This copy-like mechanism not only resembles explanations given in linguistics at a computational level; it also leads to another property that crucially defines internally merged elements: their longer availability to syntax, which leads us to the next argument.

Third, when considering the idea that the internally merged element must be available longer, *beta1* again provides an appealing parallelism. In this respect, Kopell *et al.* (2010, 2011) provide crucial insights by looking at the physiological properties of the rhythm. They note that *beta1* dependence on inhibitory rebound allows it "to continue in the absence of continuing input" (Kopell *et al.* 2010: 3), providing memory for the objects. That extra memory might be just what enables internally merged intransitive PHs to be available longer to syntax. Furthermore, Kopell *et al.* (2011) note that within *beta1*, different assemblies (at *gamma*) can co-exist without so much competition between them, which creates a context for simultaneously coding the past and present and relating temporally segregated objects. It is hard for a linguist not to read these different past and current elements as being the different relationships that the occurrences or copies of moved elements establish. So, *beta1* is perfect for comparing new and old information and putting together information from different modalities because of its wider temporal windows rather than faster rhythms (see Senkowski *et al.* 2008 and in particular Dean *et al.* 2012). The same hypothesis of an extended window of integration without further input and without much competition between elements is consistent with sustaining the *status quo* as suggested by Engel & Fries (2010) discussed above.

Furthermore, there are two additional considerations that may reinforce labeling by *beta1*: That rhythm stops when the excitation decays too much, or when it is reactivated and replaced by *beta2* and *gamma* (Cannon *et al.* 2014). From both versions of finishing the rhythm, two properties of movement could be inferred. When it decays too much, movement could be barred because of memory limitations. When the cortex is reactivated and *beta1* is replaced by *beta2*, the two *beta2* rhythms could be related to the maximum of two interpretative positions in chains (Boeckx 2012), which is usually attributed to a complete valuation of unvalued features (Chomsky 2000, 2001), barring third interpretative positions for internally moved elements.

Last but not least, when there is *beta1* in the cortex, there is less competition among assemblies (Kopell *et al.* 2011). This could be correlated to why PHs (at *beta2*) can be connected to both complements (at *gamma*) and specifiers (at *beta1*), despite the strong prohibition against *XX oscillations and categories, and to why adjuncts, which might be assemblies oscillating at *beta2*, show stronger constraints on movement or are more opaque.

To close the discussion, further support is needed for the idea that (externally merged) transitive PHs are sustained precisely by *beta2*. In this respect, the strongest argument comes simply from the complementarity of rhythms and the anatomical, dynamic, processing, and mathematic distinctions on the cortical level (as discussed above). If the hypothesis about the 'novelty' or 'familiarity' properties of objects related to *beta1* is on the right track, it makes sense to consider transitive

PHs as more familiar/less newer elements (Kopell *et al.* 2011); therefore, they do not cause *beta1*. Furthermore, if the remainder of the discussion is also on the right track, there is no space for assigning transitive PHs in the oscillatory spectral range I circumscribed the operations to. The ideal scenario would be a strong disambiguation of the functional roles of *beta1* and *beta2* rhythms, but in this respect the literature has yet to make this point clear. Thus, although we should expect further theoretical refinement, there is no significant counterargument for considering *beta2* as being the rhythm responsible for transitive PHs.

3 Ambiguous Synchrony and Short (and Apparently Long) Anti-locality

In the previous section, a way to categorially distinguish three elements as a function of the rhythms that sustain them has been developed. Non-PHs would oscillate at *gamma*, transitive PHs at *beta2* and intransitive PHs at *beta1*. As summarized in Section 1, in certain domains external systems cannot interpret *XX-like constructions. This, translated in oscillatory terms, means that certain brain structures are unable to sustain more than one of those rhythms in each band. So, the constraint can be formulated in the following way: What kind of system cannot sustain multiple rhythms in the same band?

I hypothesize that this is the case of a system that is too local or too small. The brain tends to synchronize its activity in the form of coupled oscillations (Buzsáki 2006). That coupling depends, among other factors, on the distance that separates the neurons. In other words, if the distance is long then there are only certain rhythms that are slow and powerful enough to synchronize cells. In contrast, when the structure is local/small, even fast rhythms are able to acquire the population in-phase. The latter is potentially the case for the language-specific sub-regions in external systems. Within these sub-regions, neurons are so close that their natural tendency towards synchrony forces them to be coupled even in fast rhythms. Thus, if there is a rhythm in the *beta-gamma* band, it will recruit the whole population at the specific oscillatory band regardless of whether independent neurons begin to oscillate independently. In fact, they will be synchronized far too early for multiple assemblies to be differentiated within the same band. Since labeling depends on how many of these rhythms can be sustained, only one category can be identified in each band.

If external systems, like sub-regions of Broca's areas, are local, they cannot sustain multiple rhythms in the same band without synchronizing the whole population and treating the rhythm, and consequently the neural assembly, as a single element. So, external systems cannot simultaneously sustain more than one *gamma*, more than one *beta2*, or more than one *beta1*, which, linguistically speaking, means that there cannot be more than one non-PH, more than one transitive-PH, or more than one intransitive-PH(/specifier/moved element) in certain derivational stages.

What this hypothesis implies is that: (i) the intolerable ambiguity in external systems is equal to an unavoidable and ambiguous synchronization of rhythms in brain structures and (ii) this might only happen in local/small brain regions due to conduction delays, so the locality in language can also be understood as locality in brain activity terms. Thus, we can capture one of the main language constraints or conditions, the anti-identity (Boeckx 2014a), in an implementational fashion.

This enables us to explain the linguistic manifestation of those rhythmic limited patterns, and the structural constraints of phrases and phases. It has been argued that phrases contain a maximum of one head, one complement, and one specifier (see Boeckx 2008 for a feature-valuation approach and Kayne 1994 for one in terms of linearization). My proposal about labeling and anti-identity can explain that ternary structure, as (6) makes evident. There, a maximum of three distinct elements can co-exist in a local domain: one *gamma*/complement item, one *beta2*/head item, and one *beta1*/specifier item.⁷

- (6) a. [... head [complement specifier head [...]]]
 b. [... *beta2* [*gamma beta1 beta2* [...]]]

Thanks to the unification of phrases and phases, this ternary structure above can be extended to phase-structure (7). Furthermore, the distinction between transitive and intransitive PHs into sub-bands of *beta* enables us to explain why two-phase heads can co-exist without violating the anti-identity constraint.

- (7) a. [... C [T (EA) *v* [...]]]
 b. [... transitive-PH [non-PH (intransitive-PH/edge) transitive-PH [...]]]
 c. [... *beta2* [*gamma (beta1) beta2* [...]]]

Following the logic of the present model, if we assume that there is only a maximum of one non-PH and one transitive-PH in transferred phase complements (Boeckx 2014a) (with optional specifiers as intransitive-PH embedded in the latter), it is also possible to explain the rhythmic nature of the derivation of the clausal spine, with PHs and non-PHs alternating (Richards 2010) (8). The fact is that more than one *gamma* cannot be sustained and more than one *beta2* cannot either at certain derivational stages, which forces the clausal spine to be formed in that rhythmic fashion.

- (8) a. ...[C [T *v* [V *n* [N]]]]
 b. ...[PH [non-PH PH [non-PH PH [non-PH]]]]
 c. ...[*beta* [*gamma beta* [*gamma beta* [*gamma*]]]]

Once we differentiate further between the types of PHs (transitive and intransitive), the pattern above, which is limited to a maximum of one element of a particular category in a phase complement, can explain more typical anti-identity violations. In (9a), two *beta1*/intransitive-PHs cannot coexist in that local domain. On the contrary, as (9d) shows, when we extract one of these conflicting oscillations, the rhythmic patterns become sustainable, since one of the *beta1*s then co-exists with one *beta2* in the next domain/derivational cycle.

- (9) a. *sono [queste foto del muro] [la causa della rivolta]. *Italian*
 are these pictures of-the wall the cause of-the riot
 'These pictures of the wall are the cause of the riot'

(Moro 2000)

⁷ Given an exoskeletal labeling operation (Boeckx 2014a), the constraint arises when the phase complement is transferred. In any case, the limit of elements inside the phrase is the same.

- b. *transitive-PH [non-PH(V, be) intransitive-PH intransitive-PH]
- c. **beta2* [(*gamma*) *beta1 beta1*]
- d. [Queste foto del muro sono [la causa della rivolta]]. *Italian*
these pictures of-the wall are the cause of-the riot
 'These pictures of the wall are the cause of the riot'
- e. *[intransitive-PH transitive-PH [*gamma*(V, ser) intransitive-PH]]
- f. *[*beta1 beta 2* [(*gamma*) *beta1*]]

The same logic can be extended to the ambiguous ungrammatical co-existence of two transitive PHs, which prohibits constructions like (10a). However, turning one of these transitive PHs into one intransitive PH solves the impossible sustainment of two *beta2* rhythms (10d). Furthermore, (10a) impossible sustainment of two *beta2* rhythms in locality might represent the case of adjuncts and islands, generally speaking, if we follow Boeckx's (2014a) idea that adjuncts, in contrast to specifiers, are often structurally equivalent to the transitive-PH they adjoin to. The latter could then explain the less opaque nature of specifiers to sub-extraction, for example, since *beta1* and *beta2* co-existence is possible; this is not the case with two *beta2* in adjunction.

- (10) a. *Descrībieron [a un maestro de Zen] [al papa]. *Spanish*
described to a master of zen to-the pope
 'They described a Zen master to the pope'.
 (Richards 2010)
- b. *transitive-PH [non-PH transitive-PH transitive-PH]
 - c. **beta2* [*gamma* (V, *describir*) *beta2 beta2*]
 - d. Descrībieron [un maestro de Zen] [al papa]. *Spanish*
described a master of zen to-the pope
 'They described a Zen master to the pope'.
 - e. transitive-PH [non-PH intransitive-PH transitive-PH]
 - f. *beta2* [*gamma* (V, *describir*) *beta1 beta2*]

Given the potential equivalence between anti-identity and anti-locality discussed in Section 1, the same explanation given for (9)—(10) can account for *XX conflicts in structures like (11). If such an hypothesis is on the right track, it could offer "the kind of 'deeper' explanation on independent grounds" that Grohmann (2011: 271) pursues.⁸

⁸ However, the repair strategy of spelling out the lower occurrence of the conflicting element is not transparent.

... [John_i likes himself_i]. (adapted from Grohmann 2011)
 ... [intransitive-PH non-PH ??]
 ... [*beta1 gamma* ??]

I leave this issue open to future research. Speculatively, it must have to do with the insertion of an adjunct element oscillating at *beta2*. At first glance, this would cause a conflict with the ph(r)ase head within the domain, which would be labeled by the same band. Nevertheless, a forced transfer like in the case of adjunction discussed in the context of (10a) may be resorted to.

- (11) a. *... [John_i likes t_i].
 (adapted from Grohmann 2011)
 b. *... [intransitive-PH non-PH intransitive-PH]
 c. *... [*beta1 gamma beta1*]

Finally, if we continue to assume that internally merged elements are held by *beta1*, we can also explain the *XX intervention effect of movement discussed in Section 1. Chomsky (2013) notes that labeling problems with XP—XP structures can be extended to constraints on movement over intervening elements. All we have to do is reduce locality across domains to locality within domains, represented by the cyclic nature of IM. As (12) makes clear, when one *beta1* internally merged element coexists in a derivational stage with another one, *XX constraints arise in the form of two *beta1*. As detailed earlier, both oscillations are impossible to sustain, because we are again trying to sustain two rhythms in the same (*beta1*) band, and a minimality effect arises.

- (12) a. *How do you wonder [who (how) *v* [behaved (how)]]?
 (Rizzi 2011)
 b. * PH [... intransitive-PH intransitive-PH transitive-PH [non-PH...]]
 c. * *beta2* [... *beta1 beta1 beta2* [*gamma*...]]

Despite its empirical and explanatory reach, my model faces a problem: There is no anti-identity violation when, due to cyclic IM, one moved element co-exists with one specifier (13).

- (13) a. How do you think ... [he (how) *v* [behaved (how)]]?
 b. PH [... intransitive-PH (intransitive-PH) transitive-PH [non-PH ...]]
 c. *beta2* [... *beta1 beta1 beta2* [*gamma*...]]

My model predicts an anti-identity effect between *he* and the second occurrence of *how* in (13), given that both are sustained by *beta1* and there is a moment in the derivation when they co-exist. However, the intervention between *he*, the presumed probe of C, and the goal *how*, in Chomsky's (2001) terms, does not cause a minimality effect. What might be the solution then? In Ramírez (2014), I offer an alternative account for specifiers. I argue that they are synchronized with the PH to which they are merged under a single *beta* rhythm. This possible synchronization would explain (i) why binarity is respected in the transfer of elements, contrary to the triplets we observe, (ii) why specifiers are embedded in their heads, and (iii) why they are more integrated than adjuncts, which in contrast would be impossible to be coupled to the PH (speculatively, due to conduction delays). Although that view would still account for constraints on internally merged elements, as long as we sustain their equivalence to *beta1*, differentiating them from specifiers and intransitive PHs would imply that we lose the explanatory power regarding the ternary structure of phrases and phases. Another option would be to increase the number of bands that label items, for instance, resorting to the range from slow to fast *gamma*. That theoretical possibility would be arbitrary without detailed justification and reduce the explanatory power that the above commonalities offer.

However, the problem my proposal faces here is not exclusive to it. One of the lessons in generative linguistics is that the more linguistic data are analyzed in detail, the more exceptions to explanatory theories there are. The phenomena of adjuncts, specifiers, islands, and so on are not fully satisfied nor in Kayne (1994) nor in Uriagereka (1999). Nevertheless, it does not prevent these theories from being some of the most elegant and inspirational ones to have led investigations in the field. Relatively speaking, we should not simply discard the present model because of some counterarguments from data coming from isolated linguistic debates (but see Leivada 2015 for discussion from a biolinguistic approach, and see Section 5 about experimental data). In this respect, inspiration may come from cognitive neuroscience: Conflicting evidence about the functional role of *alpha* oscillations did not discourage pursuing good intuitions; on the contrary, they have led to fruitful debates and a much deeper understanding of rhythm (see Palva & Palva 2007, 2011, and references therein).

It may be better to leave conflicting data to further inquiry, since it has been shown that the ambiguous synchronization of oscillations in local brain structures can potentially account for the ternary structure of phrases (6) and phases (7), the rhythmic nature of clausal linguistic structures (8), anti-identity constraints (9)—(10) extendable to adjuncts in the case of transitive PHs, anti-locality (11), and intervention effects in IM (12). Crucially, just a single common principle can explain the main linguistic properties: The brain synchronizes its activity (locally). The degree of plausibility in that kind of explanation allows it worth pursuing, even if this paper turns out to be completely wrong in its implementation.

4 From Global to Local: Periphery Constraining the Core

The present model also represents, in a seductive way, a lax interpretation of the distinction between I-language and E-language (Chomsky 1986). I-language should be understood here as a global, domain-general computational system, while E-language would be a more local and specific system or an interface which the former connects to. Before transfer to external systems, a domain-general large-scale core set of regions would be used. Thus, we work on a global scale that governs the freer syntax of I-language. However, after transfer, when rhythms are circumscribed to the cortical limitations of external systems, we move to local structures and to sub-regions of the Broca—Wernicke network. We are, in fact, moving from global to local in that transition to what can be represented in E-language. That E-language domain would impose constraints which cannot be expected in the network of I-language because the latter has more computational power thanks to the subcortical sources of slower rhythms.

The neural syntax in both language core and periphery is then governed by the same principles. It is only because of the locality of the structures involved in E-language that we cannot exploit the full potential that large-scale structures offer. As a result, ambiguities arise. That might reflect one of the main advantages of recruiting subcortical sources of slow rhythms: They offer the potential to govern the syntax of language of thought by means of *alpha* and *theta* (and *beta*) oscillations as well (whose presence in the cortex may need subcortical collaboration), which enables a neural syntax exempt from the limits of small regions and, consequently,

of a higher complexity.

This kind of constraint at certain local and peripheral structures of a system can be exploited by other theories which deal with locality conditions and capacity limits. As mentioned earlier, these kinds of cognitive limitations have been approached from different perspectives, for instance: (1) regarding the limits of global workspace for consciousness, Min (2010) argues that the limited capacity of attention and consciousness is due to the mechanical limitations of the thalamic reticular nucleus synchronizing processes;⁹ (2) regarding attention, Miller & Buschman (2013) speak broadly about a limited 'bandwidth'; (3) regarding working memory limits, Lisman (2010) argues for a maximum of 7 ± 2 *gamma* cycles representing items embedded in a single *theta* cycle, which is exportable to the limitation to 4 items in the interaction of *gamma* and *alpha* (Roux & Uhlhaas 2014); or (4), alternatively, Palva *et al.* (2010) attribute visual working memory limits to a bottleneck effect of oscillations in a hub like the intraparietal sulcus.

Nevertheless, there is, as far as I know, no explanation like the one offered here, where the constraint does not come from the core of the system itself but rather from the periphery to which it connects. This, furthermore, is reinforced by a solid theoretical background in generative grammar that, in this respect, has not changed in recent times. The distinction between I-language and E-language has already been related to the observation that external systems impose constraints that would not otherwise be expected, such as pronouncing only one copy of internally merged elements. In sum, a complementary explanation of capacity limitations may come from peripheral structures.

5 Conclusions: The Unexplored Dimension of Broca's Problem

Joining Kopell *et al.*'s (2014) framework of 'dynamics', it seems possible to explain why cognition has certain properties and not others from the physiological constraints of its brain circuits, understood as dynamic structures with activity at a real time scale rather than as more or less static maps that are mainstream in neurolinguistics (Poeppel 2012).

This approach has drawn our attention to the temporal dimension on multiple scales of brain activity (Buzsáki 2010), which allows a mechanistic explanation of what bars certain syntactic derivations and, consequently, what defines some crucial properties of linguistic structures.

That sort of answer suits the minimalist *why* question, namely why language has certain properties and not others (Chomsky 1995). It does so from an interdisciplinary perspective, fusing neuroscience and linguistics. Such a methodology not only offers a more solid, deeper, and less falsifiable answer, but also provides bridges to other levels of research, from genome to phenome (Boeckx & Theofanopoulou 2014), since, as Siegel *et al.* (2012) suggest, brain rhythms lie just in the middle across various levels of research.

Thus, this article not only contributes to biolinguistics in the *strong sense* (Boeckx & Grohmann 2007a) along the lines of Giraud & Poeppel (2012) in the realm of phonology, but also confers theoretical plausibility and pursues Boeckx

⁹ Similarly to the present model, limits are stronger in mono-modality (language periphery) than in cross-modality (language core)

& Benítez-Burraco's (2014) invitation to explore a new dimension of Broca's problem: Brain oscillations.

It seems possible to explain that some principles can be reduced to a physical and general restriction over brain/language/mind structure: Peripheral (language) systems are far too local to sustain multiple rhythms in the same band by which elements are identified.

Of course, the present work is mainly theoretical, so hopefully some empirical testing will, in the future, shed more light on the issues at hand. As a first and specific example, electroencephalographies should not register more than one *gamma*, one *beta1* and one *beta2* oscillation in cortical sub-regions of the Broca–Wernicke network. If they were registered, they should be coupled as single oscillations in very few cycles. Alternatively, due to the interdisciplinary approach of my model, a similar locality effect could be registered in regions usually associated with other cognitive domains and even involving other (fast) rhythms. Then, support may come from neuroscience studies beyond the field of linguistics. Time will tell.

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